RESEARCH ARTICLE OPEN ACCESS

Evaluation of Solar Water Heater Performance Using Simulation Technique

S. Ramasamy*, P. Balashanmugam**R. Suresh***
**(Assistant Professor, Department of Mechanical Engineering, Annamalai University, Chidambaram-608002*
*** (Associate Professor, Department of Mechanical Engineering, Annamalai University, Chidambaram-608002*
**** Associate Professor, Department of Mechanical Engineering, Annamalai University, Chidambaram-608002*

ABSTRACT
Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is conversion of solar radiation into heat, which can be used in water heating systems. A commonly used solar collector is the flat-plate. A lot of research has been conducted in order to analyze the flat-plate operation and improve its efficiency. Thermal energy storage has always been one of the most critical components in residential solar water heating applications. However, the energy source and the demands of a house (or building) in general, do not match each other especially in solar water heating applications. So thermal energy storage is essential in the solar heating system. Therefore, in this project an attempt has been taken to summarize the investigation of the solar water heating system incorporating with Phase Change Materials (PCMs). In our project, we have studied the difference between the performance analysis of solar water heater without PCM and with PCM. The data collected from the study is analyzed using ANSYS software which helps us to understand the outputs at various temperatures and fluid velocity at various points. The result shows that this solar heater with PCM could be used for domestic purpose in the rural areas and can be economically adopted.

Keywords - Central heating system, Crystallisation process, Phase change material, Thermal energy storage, Water heating system.

Date of Submission: 13-03-2020 Date Of Acceptance: 28-03-2020

I. INTRODUCTION

Over the last two decades a wide variety of solar energy technologies have been developed through research and development, demonstration and large-scale promotion during the eighties and nineties. One of the most widespread uses of solar thermal technology is solar water heating. India is blessed with good sunshine. The country receives solar radiation amounting to over 5 x10^{15} kWh per annum with the daily average incident energy varying between 4-7 kWh per m^2depending on the location. Solar water heating systems (SWHs) have now been used for more than sixty years. Solar energy is free, environmentally clean, and therefore is recognized as one of the most promising alternative energy recourses options. Its total available value is seasonal and is dependent on the meteorological conditions of the location. The solar energy can be more attractive and reliable if associated with a heat storage system. The storage of energy in suitable forms, which can conventionally be converted into the required form, is at present day challenge to the technologists.

Since the solar energy supply is variable in daytime and zero at night, considerable amount of solar energy should be stored during the daytime to meet the demands at night. For this purpose, latent heat of fusion of Phase Change Material (PCM) is of great interest on account of high storage density and its isothermal nature of the storage process. This project is a compilation of much of practical information and performance analyses on selected PCM used in a solar water heating system. This review article is an effort to provide practical information on with PCM and without PCM.In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated. One such alternative is solar energy.

The sun is a sphere of hot intensely hot gaseous matter with a diameter of 1.39m.the solar energy strikes our planet in a mere 8min and 20 sec after leaving the giant furnace, the sun which is 1.5×1011m away. The sun is the world's largest energy resource, and solar energy is a form of renewable energy which is abundant in our environment. On average the annual solar radiation is around 5300MJ/m^2. It is also the most important of the non-conventional sources of energy because it is non-polluting and, therefore, helps in lessening the greenhouse effect. The sun has an effective blackbody temperature of 5726k.the temperature in the central region is much higher and it is estimated at 8×106 to 40×106k. In effect the sun is a continuous fusion reactor in which hydrogen is turned into helium. The sun's total energy output is 3.8×1020MW which is equal to 63MW/m2 of the sun's surface. This energy radiates outwards in all directions. Only a tiny fraction, 1.7×1014 KW, of the total radiation emitted is intercepted by the earth. However, even with this small fraction it is estimated that 30 min of solar radiation falling on the world energy demand for one year. India receive solar energy equivalent to over 5000trillion kwh/year, which is far more than the total energy consumption of the country.

Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,000[1] tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) streams out into space in all directions. Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent upon the sun.

II.BASIC PRINCIPLE OF SOLAR ENERGY

Most of the energy we receive from the sun comes in the form of the light. When this radiation strikes a solid or liquid, it is absorbed and transformed in to heat energy. The material becomes warm and stores the heat, conducts it to the surrounding material (air, water, other materials) or reradiates to other materials of lower temperature.

2.1. Solar radiation analysis

2.1.1. Structure of the sun.

The sun is a sphere of gases matter; continuously generating heat by thermo nuclear fusion reaction which convert hydrogen atom to helium atoms. The energy is radiated from the sun in all direction and a very small fraction of it reaches the earth. The energy is released in accordance with the following reaction. The principle characteristics of the sun are

Mass; M = (1.9991 ± 0.002) x1O^{30} Kg
Radius R = (6.960 ± 0.001) x10^8m
Average density =1.410 ± 0.002 g/cm^3
Temperature (average on the surface)
T = 5762 ± 50K

The structure of the sun is generally divided in to three regions. Solar interior, the photos here and the solar atmosphere. The solar interior constitutes the main mass of the sun and has gases at a pressure billion atmosphere and temperature of 8 x10^6 to 40 x 10^6 K it is almost a continuous fusion reactor with its constituent's gases as the containing vessel retained by gravitational forces. It is estimated that 90% of energy is generated in region 0 to 0.23R, where "R" is the radius of the sun.

2.1.2. Radiation at earth's surface.

Solar radiation received at the surface of the earth entirely different due to various reasons. The solar radiation which comes directly from the apparent solar disc, without reflection from another object is called direct or beam radiation. This radiation is received from the sun without the change of direction. Diffused radiation is that solar radiation received from after its direction has been changed by reflection and sun scattering by aerosols and dust molecules. All radiation incidents on a surface scattered, reflected and direct are called total radiation.

2.1.3. The Solar Spectrum

- Solar intensity outside the atmosphere: 1.36 kW/m^2
- Incident solar intensity on the atmosphere: 1.0 kW/m^2; due to absorption by water vapor, CO_2, etc.
- Radiation reaches the Earth's surface by direct radiation (focusable by mirrors) and diffuse radiation (unfocusable)
- The diffuse percentage is strongly dependent on how clear the sky is and a typical yearly average of about 30%called total radiation.

2.1.4. Solar energy an Indian perspective

With about 300 clear, sunny days in a year, India's theoretical solar power reception, on only its land area, is about 5000 Petawatt-hours per year (PWh/yr) (i.e. 5000 trillion kWh/yr or about 600 TW). The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 with about 1500–2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. For example, assuming the efficiency of PV modules were as low as 10%, this would still be a thousand times greater than the domestic electricity demand projected for 2015.

- India is endowed with vast solar energy potential. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day.

- In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m2
- India is both densely populated and has high solar insolation, providing an ideal combination for solar power in India.
- In solar energy sector, some large projects have been proposed, and a 35,000 km² area of the Thar Desert has been set aside for solar power projects, sufficient to generate 700 to 2,100 gigawatts.

2.1.5. Applications of solar energy

- Heating of buildings.
- Solar air and water heating.
- Solar distillation on small community scale.
- Solar drying or agricultural products.
- Solar cookers.
- Solar engines for water pumping.
- Food refrigeration.
- Photo voltaic conversion.
- Solar furnace.
- Solar thermal power generation.
- Industrial process heat.

D.Solar Energy Advantages and Disadvantages

2.1.6. Solar Energy Advantages

- The power source of the sun is absolutely free.
- The production of solar energy produces no pollution.
- The technological advancements in solar energy systems have made them extremely cost effective.
- Most systems do not require any maintenance during their lifespan, which means you never have to put money into them.
- Most systems have a life span of 30 to 40 years.
- Most systems carry a full warranty for 20 to 30 years or more.
- Unlike traditional monstrous panel systems, many modern systems are sleeker such as Uni-Solar rolls that lay directly on the roof like regular roofing materials.
- In 35 states, solar energy can be fed back to the utilities to eliminate the need for a storage system as well as eliminating or dramatically reducing your electric bills.
- Solar energy systems are now designed for particular needs. For instance, you can convert your outdoor lighting to solar. The solar cells are directly on the lights and can't be seen by anyone. At the same time, you eliminate all costs associated with running your outdoor lighting.

2.1.7. Solar Energy Disadvantages

The solar energy concentration is very dilute, so collectors with large surface area are needed.

- In addition, solar radiation is neither constant nor continuous for terrestrial applications (i.e., low capacity factor).
- The solar energy received depends on latitude, season, time-of-day, and atmospheric conditions.

III. SOLAR WATER HEATER

Solar Water Heater is a device that helps in heating water by using the energy from the SUN. This energy is totally free. Solar energy (sun rays) is used for heating water. Water is easily heated to a temperature of 60-80 C. Solar Water Heaters (swhs) of 100-300 liters capacity are suited for domestic use. Larger systems can be used in restaurants, canteens, guest houses, hotels, hospitals etc. A 100 liters capacity SWH can replace an electric geyser for residential use and may save up to 1500 units of electricity annually. The use of 1000 swhs of 100 liters capacity each can contribute to a peak load saving of approximately 1 MW. A SWH of 100 liters capacity can prevent emission of 1.5 tons of carbon- dioxide per year.

Solar water heating or solar hot water is water heated by the use of solar energy. Solar heating systems are generally composed of solar thermal collectors, a fluid system to move the heat from the collector to its point of usage. The system may use electricity for pumping the fluid, and have a reservoir or tank for heat storage and subsequent use. The systems may be used to heat water for a wide variety of uses, including home, business and industrial uses. Heating swimming pools, underfloor heating or energy input for space heating or cooling are more specific examples.

In many climates, a solar heating system can provide up to 85% of domestic hot water energy. This can include domestic non-electric concentrating solar thermalsystems.Residential solar thermal installations can be subdivided into two kinds of systems: compact and pumped systems. Both typically include an auxiliary energy source (electric heating element or connection to a gas or fuel oil central heating system) that is activated when the water in the tank falls below a minimum temperature setting such as 50 °C. Hence, hot water is always available. The combination of solar water heating and using the back-up heat from a wood stove chimney to heat water can enable a hot water system to work all year round in cooler climates, without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity.

Among pumped options, there is an important distinction to be made regarding the sustainability of the design of the system. This relates to what source of energy powers the pump and its controls. The type of pumped solar thermal systems which use mains electricity to pump the fluid through the panels are called low carbon solar because the pumping negates the carbon savings of the solar by about 20%, according to data in a report called "Side by side testing of eight solar water heating's" by DTI UK. However, zero-carbon pumped solar thermal systems use solar electricity which is generated onsite using photovoltaic to pump the fluid and to operate its control electronics. This represents a zero operational carbon footprint and is becoming an important design goal for innovative solar thermal systems.

3.1. Working of a solar water heater

The Sun's rays fall on the Collector Panel (a component of Solar Water Heater). A black absorbing surface (absorber) inside the collector absorbs solar radiation and transfers the heat energy to water flowing through it. Heated water is collected in a tank which is insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to thermo siphon principle. A Solar Water Heater consists of a Collector panel to collect solar energy and an Insulated Storage Tank to store hot water.

3.2. Type of solar water heater

Solar water heating systems can be classified in different ways:

- The type of collector used
- The location of the collector - roof mount, ground mount, wall mount.
- The location of the storage tank in relation to the collector
- The requirement for a pump - active vs. passive
- The method of heat transfer - open-loop or closed-loop (via heat exchanger)
- Photovoltaic thermal hybrid solar collectors can be designed to produce both hot water and electricity.

3.3. Solar Collectors

Four types of solar collectors are used for residential applications:

- Flat- plate collector
- Integral collector- storage systems
- Batch system
- Evacuated- tube solar collectors

3.4. Flat- Plate Collector

Flat plate collectors are designed to heat water to medium temperatures (approximately 140 degrees Fahrenheit) as shown in Figure1.

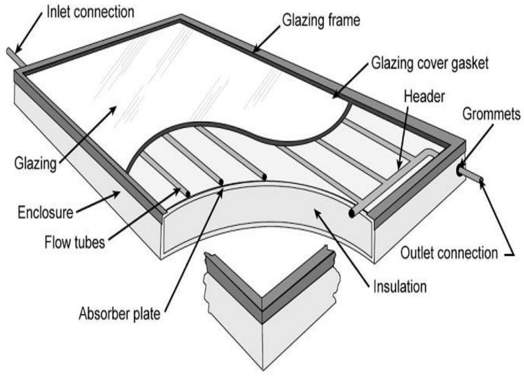

Fig.1.Flat plate collector

Flat plate collectors typically includes the following components**.**

1. Enclosure: A box or frame that holds all the components together.
2. Glazing: A transparent cover over the enclosure that allows the sun's rays to pass through to the absorber. Most glazing is glass but some designs use clear plastic.
3. Glazing Frame: Attaches the glazing to the enclosure. Glazing gaskets prevent leakage around the glazing frame and allow for contraction and expansion.
4. Insulation: Material between the absorber and the surfaces it touches that blocks heat loss by conduction thereby reducing the heat loss from the collector enclosure.
5. Absorber: A flat, usually metal surface inside the enclosure that, because of its physical properties, can absorb and transfer high levels of solar energy.
6. Flow Tubes: Highly conductive metal tubes across the absorber through which fluid flows, transferring heat from the absorber to the fluid.

3.5. Integral Collector Storage (ICS) Systems

In other solar water heating systems, the collector and storage tank are separate components. Inane integral collector storage (ICS) system, both collection and solar storage are combined within a single unit as shown in Figure 2. Most ICS systems store potable water inside several tanks within the collector unit. The entire unit is exposed to solar energy throughout the day. The resulting water is drawn off either directly to the service location or as replacement hot water to an auxiliary storage tank as water is drawn for use. Cold water flows progressively through the collector where it is heated by the sun. Hot water is drawn from the top, which is the hottest, and replacement water flows into the bottom. This system is simple because pumps and controllers are not required. On demand, cold water from the house flows into the collector and hot water from the collector flows to a standard hot water auxiliary tank within the house.

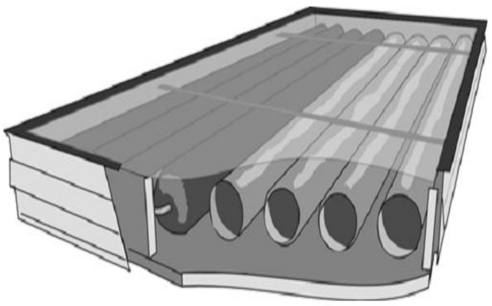

Fig. 2 .ICS Collector system

3.5.1. Batch system

The simplest of all solar water heating systems is a batch system.

- It is simply one or several storage tanks coated with black, solar-absorbing material in an enclosure with glazing across the top and insulation around the other sides as shown in Figure 3.
- It is the simplest solar system to make. When exposed to sun during the day, the tank transfers the heat it absorbs to the water it holds.

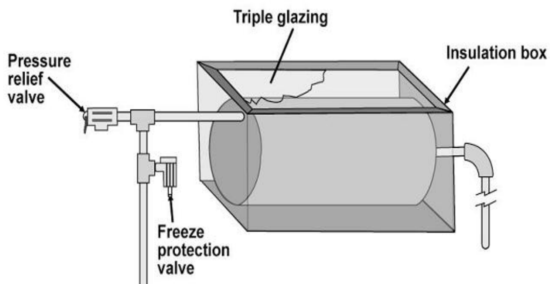

Fig. 3. Batch solar water heater

3.5.3. Evacuated Tube Solar Collectors

This type of system features parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin's coating absorbs solar energy but inhibits radioactive heat loss. These collectors are used more frequently for commercial applications. Evacuated-tube collectors generally have a smaller solar collecting surface because this surface must be encased by an evacuated glass tube. They are designed to deliver higher temperatures (approximately 300 degrees Fahrenheit). The tubes themselves comprise the following elements:

1. Highly tempered glass vacuum tubes, which function as both glazing and insulation.
2. An absorber surface inside the vacuum tube. The absorber is surrounded by a vacuum that greatly reduces the heat loss.

3.5.4. Active Solar Water Heating Systems

There are two Solar Water Heating System types:

- Active
- Passive

There are two types of Active Solar Water Heating Systems:

- Direct Circulation Systems
- Indirect Circulation Systems

3.5.5. Direct Circulation Systems

Pump circulates domestic water through the collector(s) and into the building as shown in Figure 4. This type of system works well in climates where it rarely freezes.

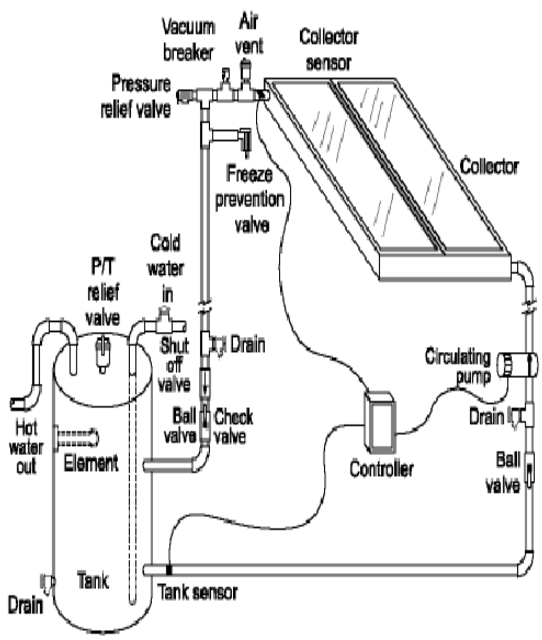

Fig .4. Direct Pumped system

The direct pumped system has one or more solar energy collectors installed on the roof and a storage tank located somewhere within the building. A pump circulates the water from the tank up to the collector and back again. This is called a direct (or open loop) system because the sun's heat is transferred directly to the potable water circulating through the collector and storage tank. Neither an anti- freeze nor heat exchanger is involved. This system has a differential controller that senses temperature differences between water leaving the solar collector and the coldest water in the storage tank. When the water in the collector is about

15- 20°F warmer than the water in the storage tank, the pump is turned on by the controller. When the temperature difference drops to about 3- 5°F, the pump is turned off. IN this way, the water always gains heat from the collector when the pump operates. A flush- type freeze protection valve installed near the collector provides freeze protection. Whenever temperatures approach freezing, the valve opens to let warm water flow through the collector. The collector should always allow for manual draining by closing the isolation valves (located above the storage tank) and opening the drain valves. Automatic recirculation is another means of freeze protection. When the water in the collector reaches a temperature near freezing, the controller turns the pump on for a few minutes to warm the collector with water from the storage tank.

3.5.6. Direct System Advantages

Service water used directly from collector loop. No heat exchanger –more efficient heat transfer to storage. Circulation pump (if needed) needs only to overcome friction losses –system pressurized.

3.5.7. Direct System Disadvantages

- Quality of service water must be good to prevent corrosion, scale or deposits in components.
- Freeze protection depends on mechanical valves.
- Recommended in climates with minimal/no freeze potential, and good water quality.

3.6. Indirect Circulation Systems

Pump circulates a non- freezing, heat transfer fluid through the collector(s) and a heat exchanger. This heats the water that then flows into the home. This type of system works well in climates prone to freezing temperatures. This system design is common in northern climates, where freezing weather occurs more frequently. An anti- freeze solution circulates through the collector, and a heat exchanger transfers the heat from the anti- freeze solution to the storage tank water as shown in Figure 5.

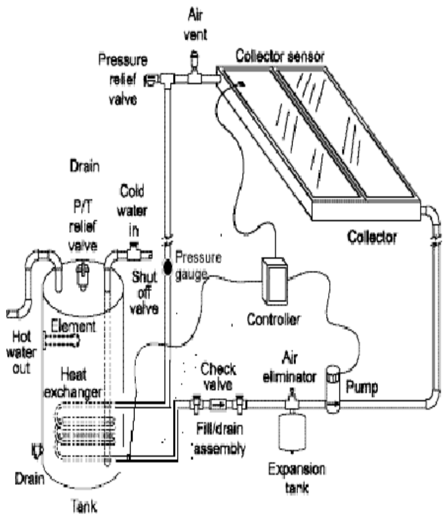

Fig .5. Indirect Circulation Systems

When toxic heat exchanger fluids are used, a double- walled exchanger is required. Generally, if the heat exchanger is installed in the storage tank, it should be located in the lower half of the tank. A heat transfer solution is pumped through the collector in a closed loop. The loop includes the collector, connecting piping, the pump, an expansion tank and a heat exchanger. A heat exchanger coil in the lower half of the storage tank transfers heat from the heat transfer solution to the potable water in the solar storage tank. An alternative of this design is to wrap the heat exchanger around the tank. This keeps it from contact with the potable water. The differential controller, in conjunction with the collector and tank sensors, determines when the pump should be activated to direct the heat transfer fluid through the collector. The photovoltaic panel located on the roof supplies the power to operate the circulating pump.

3.6.1. Indirect System Advantages

- Freeze protection provided by antifreeze fluid or drain back.
- Collector/piping protected from aggressive water.

3.6.2. Indirect System Disadvantages

- Must account for reduced heat transfer efficiency through heat exchanger.
- Added materials = added cost.
- If not using water, fluids require maintenance.
- Most designs require added pumping cost.

D. Solar Water Heater Applications

1)Domestic: Flats, Bungalows and Apartments.

2) Commercial: Hotels, Hospitals, Hostels and Dormitories.

3) Industrial: Process Industries, Preheating boiler feed water.

In domestic sector, hot water is used for bathing, washing of clothes & utensils etc. The requirement may, however, vary with the season of the year & number of family members. Our experience says hat on an average 30 to 35 liters of water at 50 to 55º C. is consumed by an individual. Thus, for a family of 4 members,125 LPD Solar Water Heating System is quite sufficient. I n commercial & industrial sectors, where large quantity of water is required at fairly high temperature.

3.7. Usage of solar water heater

Hot water heated by the sun can be used to:

- Heat water (e.g. for sanitary purposes such as showering, washing, ...)
- Generate electricity

Designs suitable for hot climates can be much simpler and cheaper, and can be considered an appropriate technology for these places. The global solar thermal market is dominated by China, Europe, Japan and India.

The typical 50 gallon electric water heater uses 11.1 barrels of oil a year, which translates into the same amount oil used by a typical 4 door sedan driven by the average consumer. Electric utility companies often provide electricity by burning and releasing energy from fuels such as oil, coal and nuclear energy. An electrical home hot water heater sits on an electrical grid and may be driving the use of unclean fuels on the other end of the grid.

IV. THERMALENERGY STORAGE WITH PHASE CHANGE MATERIAL

TES systems have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale fuel commutating. The selection of a TES system for a particular application depends on many factors, including storage duration, economics, supply and utilization temperature requirements, storage capacity, heat losses and available space. The main types of TES are sensible and latent. Sensible TES systems store energy by changing the temperature of the storage medium, which can be water, brine, rock, soil, etc. Latent TES systems store energy through phase change, e.g., cold storage water/ice and heat storage by melting paraffin waxes. Latent TES units are generally smaller than sensible storage units. More compact TES can be achieved based on storages that utilize chemical reactions.

Latent heat storage is one of the most efficient ways of storing thermal energy. In Latent TES systems, energy is stored during the phase change (e.g. melting, evaporating and crystallization). Due to the specific heat of a typical medium and the high enthalpy change during phase change, the latent heat change is usually greater than the sensible heat changes for a given system size. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with a smaller temperature difference between storing and releasing heat. Every material absorbs heat during heating process while its temperature is rising constantly. The heat stored in the material is released into the environment through a reverse cooling process. During the cooling process, the material temperature decreases continuously.

$$Q = m L$$

Where m denotes the mass and L is the specific latent heat of the PCM (Phase Change Material). Latent TES systems store energy in PCMs, with the thermal energy stored when the material changes phase, usually from a solid to liquid (for example: energy is required to convert ice to water, to change water to steam and to melt paraffin wax. The most common example of latent TES is the conversion of water to ice. Cooling systems incorporating ice storage have a distinct size advantage over equivalent-capacity chilled-water units became of the relatively large amount of energy that is stored through the phase change. For minus (cold) temperature, PCMs (i.e. ice), the liquid to solid (freezing) change absorbs energy and the solid to liquid change releases that absorbed energy. On the other hand, for positive (hot) temperature PCMs, the solid to liquid change absorbs energy and the liquid to solid change releases that absorbed energy, and does so at constant temperatures. In each case, the amount of energy absorbed and released is termed as latent heat. Phase change process of PCM from solid to liquid and vice versa is schematically shown in Figure 6.

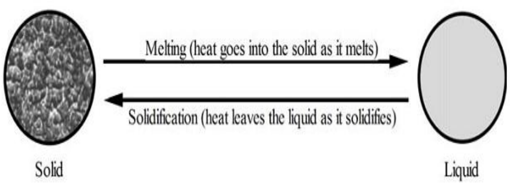

Fig .6. Phase Change Material

The large heat transfer during the melting process as well as the crystallization process without significant temperature change makes PCM interesting as a source of heat storage material in practical applications. When temperature increases, the PCM microcapsules absorbed heat and storing this energy in the liquefied phase change materials. When the temperature falls, the PCM microcapsules release this stored heat energy and consequently PCM solidify. The energy required to cause these changes is named the heat of fusion at the melting point and the heat of vaporization at the boiling point. The specific heat of fusion or vaporization and the temperature at which the phase change occurs are very important in design phase. CMS are either packaged in specialized containers such as: tubes, shallow panels, plastic bags; or contained in conventional building elements such as: wall board and ceiling; or encapsulated as self-contained elements. The aim of this research paper was to provide a compilation of practical information on different PCMs and systems developed for thermal management in residential and commercial establishments based on TES technology in building energy system.

4.1. Type of PCMs

A large number of phase change materials (organic, inorganic and eutectic) are available in any required temperature range. A classification of PCMs is given in Figure 7. There are a large number of organic and inorganic chemical materials, which can be identified as PCM from the point of view melting temperature and latent heat of fusion. However, except for the melting point in the operating range, majority of phase change materials does not satisfy the criteria required for an adequate storage media as discussed earlier. As no single material can have all the required properties for an ideal thermal-storage media, one has to use the available materials and try to make up for the poor physical property by an adequate system design. For example, metallic fins can be used to increase the thermal conductivity of PCMs, supercooling may be suppressed by introducing a nucleating agent or a 'cold finger' in the storage material and incongruent melting can be inhibited by use of suitable thickness. In general, inorganic compounds have almost double volumetric latent heat storage capacity (250-400 kg/dm^3) than the organic compounds (128-200 kg/dm^3). For their very different thermal and chemical behavior, the properties of each subgroup which affects the design of latent heat thermal energy storage systems using PCMs of that subgroup are discussed in detail below.

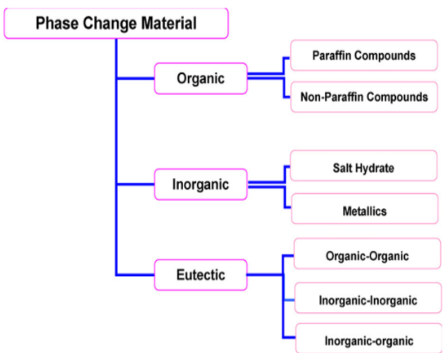

Fig .7. Phase Change Material

4.2. Organic phase change materials

Organic materials are further described as paraffin and non-paraffin. Organic materials include congruent melting means melt and freeze repeatedly without phase segregation and consequent degradation of their latent heat of fusion, self-nucleation means they crystallize with little or no supercooling and usually non-corrosiveness.

4.2.1. Paraffin

Paraffin wax consists of a mixture of mostly straight chain n- alkanes CH_3-(CH_2)-CH_3. The crystallization of the (CH_3) - chain release a large amount of latent heat. Both the melting point and latent heat of fusion increase with chain length. Paraffin qualifies as heat of fusion storage materials due to their availability in a large temperature range. Due to cost consideration, however, only technical grade paraffin's may be used as PCMs in latent heat storage systems. Paraffin is safe, reliable, predictable, less expensive and non-corrosive. They are chemically inert and stable below 500 °C, show little volume changes on melting and have low vapor pressure in the melt form. For these properties of the paraffins, system-using lists thermal properties of some technical grade paraffin, which are essentially, paraffin mixtures and are not completely refined oil. The melting point of alkane increases with the increasing number of carbon atoms. Apart from some several favorable characteristics of paraffins, such as congruent melting and good nucleating properties.

They show some undesirable properties such as: (i) low thermal conductivity, (ii) non-compatible with the plastic container and (iii) moderately flammable. All these undesirable effects can be partly eliminated by slightly modifying the wax and the storage unit.

4.2.2. Non-paraffins

The non-paraffin organic is the most numerous of the phase change materials with highly varied properties. Each of these materials will have its own properties unlike the paraffin's, which have very similar properties. This is the largest category of candidate's materials for phase change storage. Fatty acids, alcohol's and glycol's suitable for energy storage. These organic materials are further subgroups as fatty acids and other non-paraffin organic. These materials are flammable and should not be exposed to excessively high temperature, flames or oxidizing agents.

4.3. Inorganic phase change materials

Inorganic PCMs have some attractive properties including: high latent heat values; higher thermal conductivity; not flammable; lower in cost in comparison to organic compounds; high water content means that they are inexpensive and readily available. However, their unsuitable characteristics have led to the investigation of organic PCMs for this purpose. These include: corrosiveness; instability; improper re-solidification; suffer from decomposition and super cooling affects their phase change properties. As they require containment, they have been deemed unsuitable for impregnation into porous building materials.

Nucleating and thickening agents can be added to Inorganic Phase change materials to minimize super cooling and decomposition. Unlike conventional sensible thermal storage methods, PCMs provide much higher energy storage densities and the heat is stored and released at an almost constant temperature. PCMs can be used for both active and passive space heating and cooling systems.

4.3.1. Salt hydrates

Salt hydrates may be regarded as alloys of inorganic salts and water forming a typical crystalline solid of general formula $ABnH_2O$. The solid-liquid transformation of salt hydrates is actually a dehydration of hydration of the salt, although this process resembles melting or freezing thermodynamically. A salt hydrates usually melts to either to a salt hydrate with fewer moles of water, i.e.

AB •nH2O ! AB • mH2O + *(n* — m)H2O

or to its anhydrous form

AB •nH_2O ! AB + nH_2O

At the melting point the hydrate crystals breakup into anhydrous salt and water, or into a lower hydrate and water. One problem with most salt hydrates is that of incongruent melting caused by the fact that the released water of crystallization is not sufficient to dissolve all the solid phase present. Due to density difference, the lower hydrate (or anhydrous salt) settles down at the bottom of the container. Most salt hydrates also have poor nucleating properties resulting in supercooling of the liquid before crystallization beings. One solution to this problem is to add a nucleating agent, which provides the nucleion which crystal formation is initiated. Another possibility is to retain some crystals, in a small cold region, to serve as nuclei.

Salt hydrates are the most important group of PCMs, which have been extensively studied for their use in latent heat thermal energy storage systems. The most attractive properties of salt hydrates are: (i) high latent heat of fusion per unit volume, (ii) relatively high thermal conductivity (almost double of the paraffin's), and (iii) small volume changes on melting. They are not very corrosive, compatible with plastics and only slightly toxic. Many salt hydrates are sufficiently inexpensive for the use in storage.

4.3.2. Metallics

This category includes the low melting metals and metal eutectics. These metallics have not yet been seriously considered for PCM technology because of weight penalties. However, when volume is a consideration, they are likely candidates because of the high heat of fusion per unit volume. They have high thermal conductivities, so fillers with added weight penalties are not required. The use of metallics poses a number of unusual engineering problems. A major difference between the metallics and other PCMs is their high thermal conductivity. Some of the features of these materials are as follows:

- Low heat of fusion per unit weight.
- High heat of fusion per unit volume.
- High thermal conductivity.
- Low specific heat.
- Relatively low vapor pressure.

4.3.3. Eutectics

A eutectic is a minimum-melting composition of two or more components, each of which melts and freeze congruently forming a mixture of the component crystals during crystal-lization. Eutectic nearly always melts and freezes without segregation since they freeze to an intimate mixture of crystals, leaving little opportunity for the components to separate. On melting both components liquefy simultaneously, again with separation unlikely. Some segregation PCM compositions have sometimes been incorrectly called eutectics, since they are minimum melting. Because of the components undergoes a peritectic reaction during phase transition, however, they should more properly be termed peritectic. Freezing point of the mixture of tetradecane (m.p.5.3 °C) and hexadedane (m.p. 17.9 °C). The eutectic point of laboratory grade hexadecane- tetradecane mixture occurs at approximately 91.67% of tetradecane, and its phase change temperature is approximately 1.7 °C.

4.4. Property of PCMs

4.4.1. Thermodynamic properties

- Large enthalpy of transition with respect to the volume of the storage unit;
- High change of enthalpy near temperature of use;
- Phase change temperature fitted to application;
- The latent heat should be as high as possible to minimize the physical size of the heat storage;
- High latent heat of fusion per unit mass, so that a lesser amount of material stores a given

amount of energy;

- A melting point in the desired operating temperature range;
- Fixed and clearly determined phase change temperature (freeze/melt point);
- Congruent melting point to avoid segregation;
- Lower change of volume during phase change;
- High density, so that a smaller container volume holds the material
- High thermal conductivity (both liquid and solid phases) would assist the charging and discharging of the energy storage high specific heat.

4.4.2. Kinetic properties

- Little or no undercooling during the freezing process;
- Sufficient crystallization rates.

4.4.3. Chemical properties

- No chemical decomposition, so that the latent TES system life is assured;
- Non-corrosiveness to construction material;
- Long term chemical stability;
- Non-poisonous; Non-toxic;
- Non-explosive, non-dangerous;
- Non-flammable.

4.4.4. Physical properties

- High density with low density variation;
- Small units' size;
- Low vapour pressure,
- Favourable phase equilibrium.

4.4.5. Economic properties

- Available in large quantities;

V. EXPERIMENTAL SETUP

5.1. Solar surveying

Before installation of any solar heating system, a brief solar surveying should be done at the project site, to ensure the site receives proper sunlight and there are no blockages in the horizon (example: trees, tall buildings etc.) that could block the sun. For the purpose of surveying we need an inclinometer a compass and a Sun chart. An inclinometer/clinometer gives the inclination of an object/tree in the distant horizon. For the purpose of our work, a handmade inclinometer was used, which consisted of a cardboard sheet with a figure of a reverse protractor with marked angles glued to it. The center of the cardboard protractor has a hole through which a load is suspended. The viewer observes the object along the line sight line and the angle that the suspended load makes with the 0° mark, gives the inclination of the object. Simultaneously the azimuth angle is to be measured for the object. The azimuth angle is nothing but the angle that the object makes with the south direction in the horizontal plane. It can be easily found out using a compass.

5.2. The collector's orientation

For the best performance collectors are always placed at a 12° inclination with the ground. Collectors cannot face east/west direction, as the problems of shading would occur in the evening and morning hours. During winter the sun's path in the sky goes more toward the South Pole. So, for using the sun's rays to the maximum limit we have to make the collectors face south direction. We used software: -to confirm the fact that collectors facing south direction during winter months in India would never experience shade at any time of the day.

5.3. Specifications

collector size:1.0 m x 0.5 m x 0.0015 m
number of tubes : 5
length of each tubes : 1.0 m
diameter of the tube : 0.00127 m
thickness of the tubes : 0.002 m
thickness of the glass plates : 0.003 m
tube material : stainless steel (304) tube
radiation absorber material: stainless steel (304)
collector insulation: cellular foam.
Pcm Material : om 53.
mass of pcm : 4.5 Kg

5.4. Construction of the solar collectors

A solar collector consists of 6main parts. They are described below

5.4.1. The absorber

This is a dull-black painted metal body on which the pipe containing the water is fixed. The black coating absorbs almost all the solar radiation that falls on it. The collected radiation is transformed into heat and simultaneously heats the water inside. Temperatures of 100 °C or more can be reached.

5.4.2. The casing or collector box

The absorber is put into a box made of wood with a depth of 10 to 15 cm. The absorber is adjusted about half way the total depth so that there is sufficient space underneath as well as above the absorber.

5.4.3. The insulation layers

The space underneath the absorber is filled with insulation material that retains the heat of the absorber. Usually the insulation layer should be about 5 cm thick.

5.4.4. The cover sheets

To retain the heat in the collector, the box is covered by glass. Thickness of the glass-sheet must be at least 3 to 4 mm. The glass-sheet allows sunshine to pass through without absorbing too much solar radiation. Also, it prevents the cooling of air by wind.

5.4.5.PCM capsules

The PCM capsules are fixed to the down side of the solar flat plate collector. The capsules are in fitted in back side of water tubes. The totally 12 capsules we used in this project. All capsules have same size 200x50x50 MM^3. The stainless-steel capsules were coated with non-selective black paint then placed in the middle of collector arranged inline single row in the cross flow of pumped water. Spaces opened between the capsules to increase the heat exchanging to the pumped water.

5.4.6. Water tubes

In this project, the no of tubes 5 which are made by stainless steel. The length of tubes is 1 meter and thickness 2mm. The tubes are fitted on the surface of flat plate collector. The water circulated in the tubes as shown Figure 8.

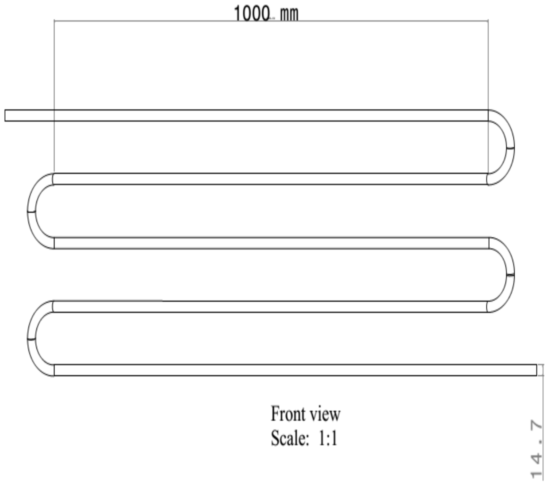

Fig.8. Water tubes

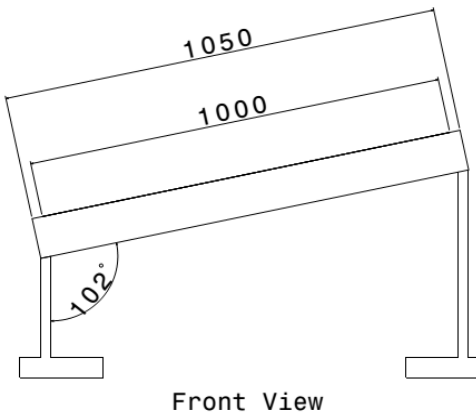

Fig.9. Front view of Solar water heater

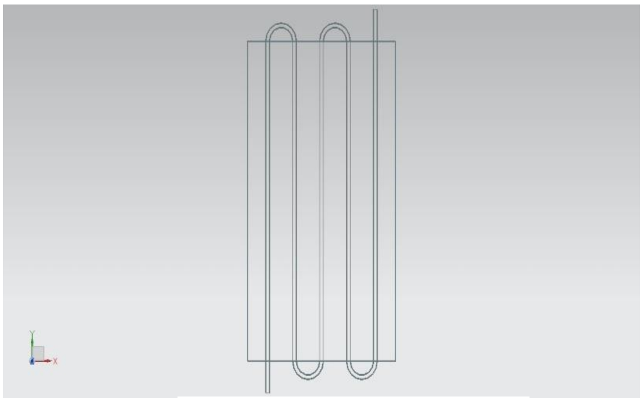

Fig .10. Solar water heater without PCM

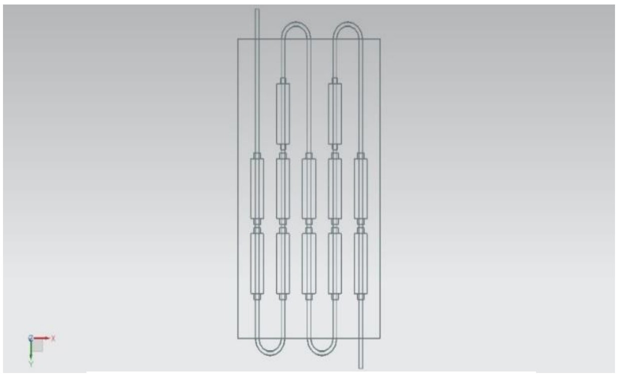

Fig .11. The flat plate collector with PCM

The total setup is placed at an angle 12° to the horizontal. Feed water pass through the absorber plate and it's heated by solar energy. The water and condenses on the inner sided of the glass plate after releasing the latent heat. A heat reservoir with 1 cm thickness is integrated with the solar water heater a filled by a phase change materials PCM. That acts as a latent heat storage subsystem. Paraffin wax was selected as a PCM due to its thermal storage, safety, reliability, and low cost during the sunshine, when the absorber temperature is higher than the temperature of PCM. The heat is transferred to the PCM and charging process is started to store solar energy as a latent heat till PCM reaches its melting temperature. Additional charging heat is stored as the latent heat during the melting process, when the absorber temperature is lower than PCM (after sunset) reverse process is occurred (discharging process) till the PCM layer is fully solidified. The thermocouple is used to measure the temperature of the glass plate, absorber plate, water and phase change material temperature, the quantity of distilled water is going to be measured.

The performance of Solar Water Heater with and without use of Phase Change material was compared on typical sunny days as shown in Figures.9,10, and 11. The experiments were carried out in the solar water heater with the without Phase Change Material (PCM) simultaneously from

18.4.2019 to 19.4.2019. The Following observations like Solar Intensity, Flow Rate, Absorber Plate Temperature (Tp), Glass Plate Temperature (Tg), Water Temperature (Tw), Phase Change Material Temperature (Tpcm), Ambient Temperature (Ta) have been made and recorded.

VI. Overview of ANSYS

A thermal analysis calculates the thermal distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are:

- The temperature distribution.
- The amount of heat lost or gained.
- Thermal gradient.
- Thermal fluxes.

Thermal simulations play an important role in the design of many engineering application, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components.

The following analysis topics available:

- How ANSYS treats thermal modelling.
- Types of thermal analysis.
- Coupled-field analysis.
- About GUI paths and command syntax.

6.1. How ANSYS treats thermal modeling

The basics for thermal analysis in ANSYS are a heat balance equation obtained from the principal of conservation of energy. The finite elements solutions you perform via ANSYS calculates nodal temperatures, the uses the nodal temperature to obtain other thermal quantities. Ansys Program handles the three modes of heat transfer i.e. convection, conduction and radiation.

6.2. Types of thermal analysis.

6.2.1. Steady – state thermal analysis

Determines the temperature distribution and other quantities under steady – state loading condition. A steady- state loading condition is a situation where heat storage effect varying over a period of time can be ignored.

6.2.2. Transient thermal analysis

Determine the temperature distribution and other thermal quantities under condition that vary over a period of time.

6.3. Directed heat Flux

This capability provides the ability to model phenomena such as diurnal heating. This capability is defined using the Model | Load | Elemental | Heat Flux operation with the Directional option chosen. The required input for this capability is: the magnitude of the flux vector, the absorptivity of the surface on which the flux is being applied, and the vector components of the flux vector. The absorptivity can be either constant with respect to temperature or can be dependent on temperature. The magnitude and components of the heat flux can be fixed or functions which vary with time. An additional input of the temperature of the radiant heat source is provided on the input form. This temperature is not currently used and is available for future use in wavelength dependent absorptivity.

6.4. Steady State Thermal Analysis of Solar Water Heater without PCM

A model of solar water heater without PCM as shown in Figures 12,13,14 and 15. Temperature distribution of water in water tube without PCM in day time and night time is shown in Figures 16 and 17.

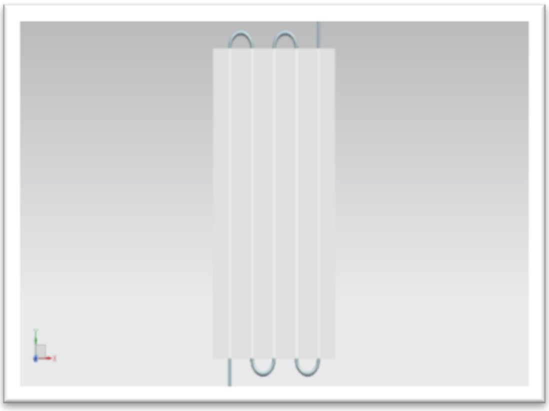

Fig.12. Solar Panel with tubes

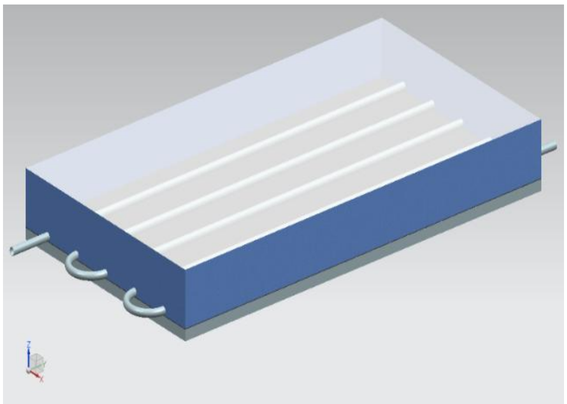

Fig.13. Solar flat plate system

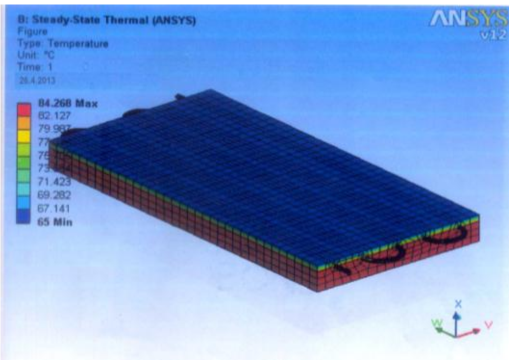

Fig.14. Heat flux

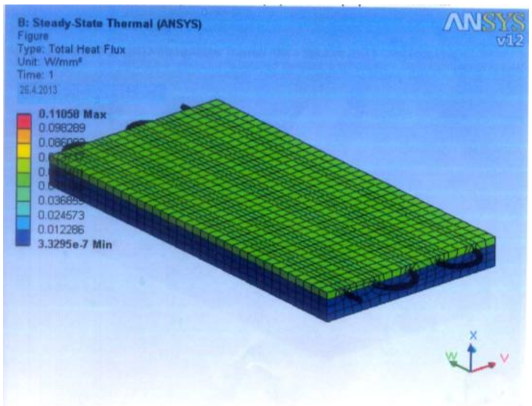

Fig. 15. Directional heat flux

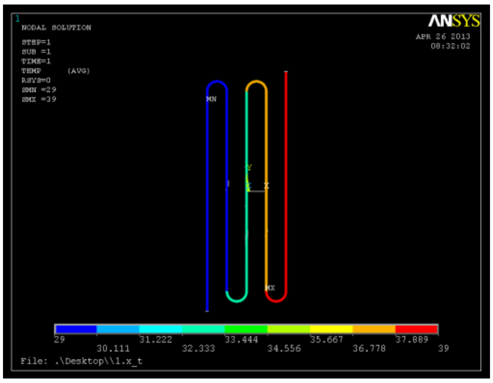

Fig. 16. Temperature distribution of water in water tube without PCM in day time

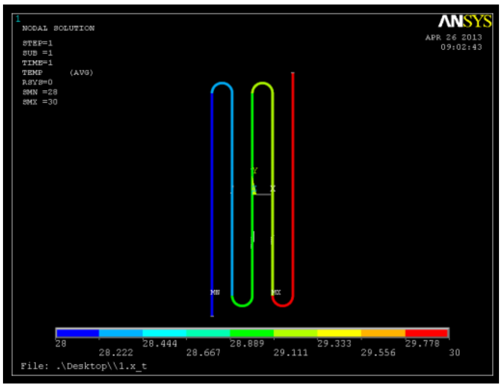

Fig.17. Temperature distribution of water in water tube without PCM in night time

6.5. Steady State Thermal Analysis of Solar Water Heater with PCM

A model of solar water heater with PCM is shown in Figures 18 and 19. The temperature distribution of water in water tubes at day time with PCM and night time with PCM as shown in Figures 20 and 21.

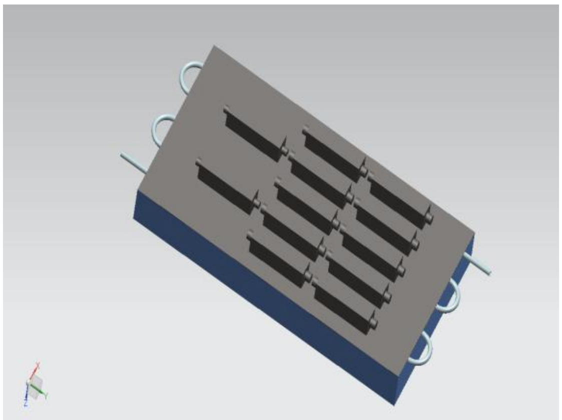

Fig. 18. Model for Solar flat plate with PCM

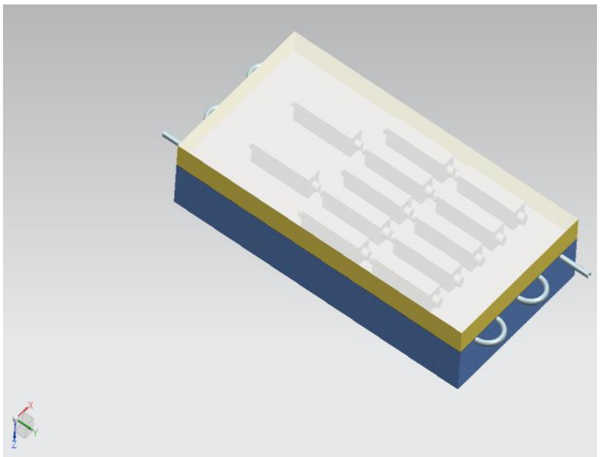

Fig. 19. Model for Solar flat plate with PCM

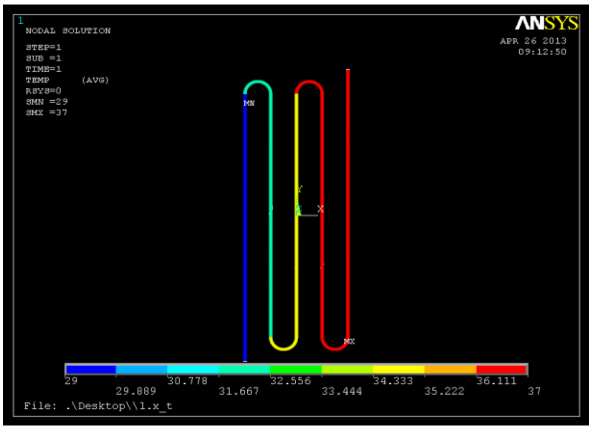

Fig.20. Temperature distribution of water in water tubes at day time with PCM.

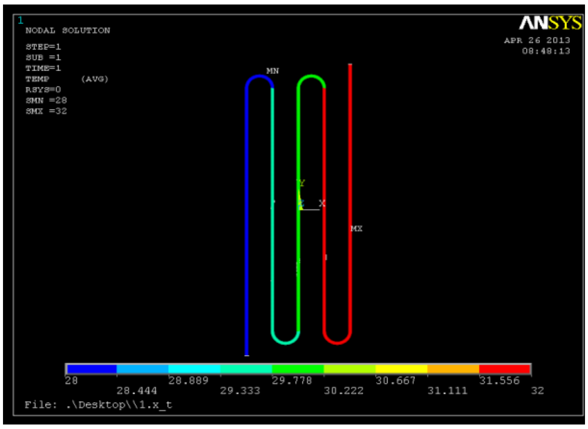

Fig.21. Temperature distribution of water in water tubes at night time with PCM

Total heat flux and direct heat flux in solar water heater with PCM is shown in Figures 22 and 23.

Fig.22. Total Heat Flux

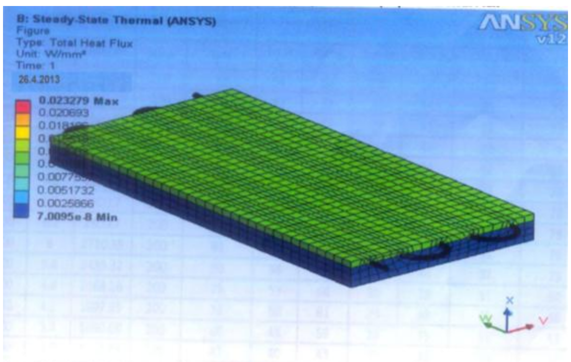

Fig. 23. Directional Heat Flux

VII. RESULTS AND DISCUSSION

An Experiment study were carried out on sunny days to compare the thermal performance of solar water heater with and without PCM in Annamalai Nagar city, Tamilnadu. The following result was found with the analysis. The full view of solar water heater without PCM is shown in Figure 24. The maximum and minimum temperature of solar water heater without PCM is presented in the table1.

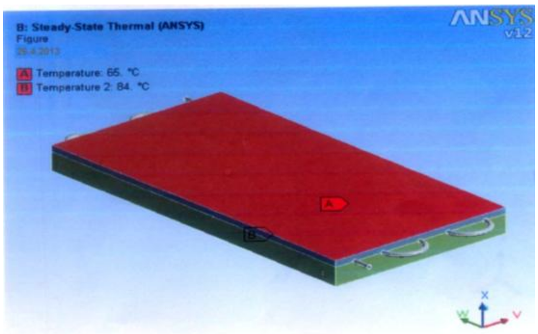

Fig.24. Full view of solar water heater without PCM

Table 1: Result tabulation of solar water without PCM

Minimum	65 °C	3.329 5e^{-007} W/mm^2	- 6.733 e^{-002} W/mm^2
Maximum	84.2 68°C	0.110 58 W/mm^2	6.31 62e^{-002} W/mm^2
Minimum occurs on	Glas s	Insulat ion	Tube
Maximum occurs on	Flat Plate Collector		

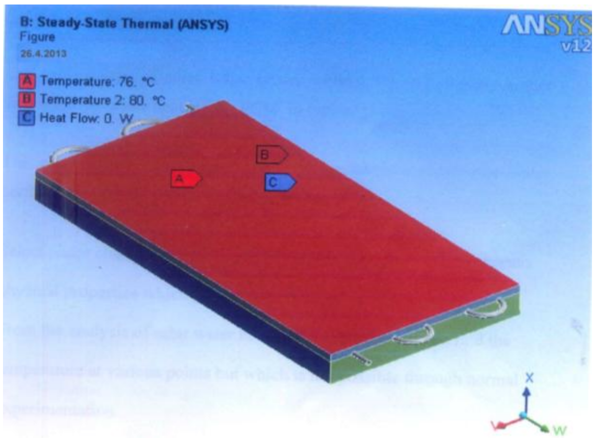

Fig.25. Full view of solar water heater with PCM

The full view of solar water heater with PCM is shown in Figure 25. The maximum and minimum temperature of solar water heater with PCM is presented in the table 2.

Table:.2 Result tabulation of solar water heater with PCM

Results			
Minimum	**76 °C**	**7.0095e^{-007} W/mm^2**	**-1.417 e^{-002} W/mm^2**
Maximum	**80.057°C**	**2.3279e W/mm^2**	**1.3297e^{-002} W/mm^2**
Minimum occurs on	**GLASS**	**INSULATION**	**TUBE**
Maximum occurs on	**FLAT PLATE COLLECTOR**		

By the Ansys software we can defined

- the glass plate temperature is low compare to Flat plate collector temperature.
- the total heat flux is low in insulator and higher in Flat plate collector.

VIII. CONCLUSION

- The performance of solar water heater without PCM is slightly higher than the solar water heater with PCM in typical sunny days.
- The solar water heater with PCM causes enhancement of solar water performance especially during night periods.
- Select phase change material for the system which was excellent thermo physical properties which yields higher productivity.
- From the analysis of solar water heater through ansys we can find the temperature at various points but which is not possible through normal experimentation.

REFERENCES

[1]. Atul Sharma, V.V. Tyagi, C.R. Chen and D. Buddhi, “Review on thermal energy storage with phase change materials & applications.” Renewable and Sustainable Energy Reviews 13 (2009) p.n.318–345.

[2]. Abhat A,Shamsunder N,“Low temperature latent heat thermal energy storage: heat storage materials”. Solar Energy 1981;30(4) p.n.313–32.

[3]. Lane GA, Glew DN, “Heat of fusion system for solar energy storage. In: Proceedings of the workshop on solar energy storage subsystems for the heating and cooling of buildings.” Virginia Charlothensville; 1975.p.n 43–55.

[4]. Swet CJ, C. Thomas “Phase change storage in passive solar architecture” In Proceedings of the 5th national passive solar conference, 1980.p.n 282–6.

[5]. Lane GA and etc all “Solar heat storage—latent heat materials” vol. I. Boca Raton, FL: CRC Press, Inc.; 1983

[6]. John Welty and etc all, “Fundamentals of Momentum, Heat, and Mass Transfer, 3rd edition”, John Wiley & Sons, p.252-295.

[7]. Lindon, C. Thomas, “Heat Transfer”, Prentice-Hall International, Inc., p.34-256

[8]. John H Lienhard and etc all “A Heat Transfer Textbook”, phlogiston press, p.139-266.

[9]. Daryl L. Logan, "A First Course in the Finite Element Method”Edition 4, illustratedPublisher Cengage Learning, 2007.

[10]. Robert L. Woods, Kent L. Lawrence, "Modeling and simulation of dynamic systems" University of Michigan Prentice Hall, 1997.

[11]. John R. Baker, “ANSYS EXERCISE– Temperature Distribution in a Plate” second published 2001 ANSYS 8.1.

[12]. Y. Nakasone and S. Yoshimoto, "Engineering Analysis with ANSYS Software" Department of Mechanical Engineering Tokyo University of Science, Tokyo, Japan First published 2006.

[13]. Liz Marshal, JohnKrouse, Susan Wheeler, "Welcome to ANSYS Advantage” Volume I, Issue 1, 2007.

[14]. Kent L. Lawrence, " ANSYS Tutorial Release 7.0" Publisher Schroff Development Corporation, 2002.

[15]. Kent L. Lawrence, “ANSYS Workbench Tutorial: Structural & Thermal Analysis Using the ANSYS Workbench Release 12.1 Environment”SDC